Osteoarthritis and Cartilage (2002) **10,** 542–546

1063–4584/02/$35.00/0
doi:10.1053/joca.2002.0809, available online at http://www.idealibrary.com on IDEAL®

Osteoarthritis and Cartilage

International Cartilage Repair Society

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Quantitative assessment of joint space width with an electronic caliper

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Summary

The progression of joint space narrowing (JSN) is considered to be the best available marker of osteoarthritis (OA) progression. Several techniques have been proposed for the measurement of joint space at its narrowest point in OA of the hips and knees.

Objective: To evaluate the properties of the technique using an electronic caliper for the measurement of JSN in OA patients.

Design: We used an electronic caliper to measure joint space width (JSW) for hips on 100 plain radiographs. JSW was measured in the vertical position at the center of the femoral head. Femoral head diameter was also determined to correct for variations due to differences in magnification of digitized X-rays. All films were read twice by each of two rheumatologists (one junior, one senior) and two radiologists (one junior, one senior). Intraclass correlation coefficients and their 95% confidence intervals were calculated.

Results: Detailed results are given for right hips (38 with OA, 18 inflammatory, 44 normal); very similar results were obtained for left hips. For JSW, the intraclass correlation coefficient was between 0.96 and 0.99 for intraobserver reliability. The level of reliability was similar for analysis of the diameter of the femoral head (R:0.84 to 0.98) and for the ratio of these two measurements (0.96 to 0.99). The most reliable measurements were those made by the senior radiologist, followed by those made by the two rheumatologists. In assessments of interobserver reliability for the measurement of JSW, R varied from 0.91 to 0.96 for the first reading and from 0.88 to 0.96 for the second reading. For the measurement of femoral head diameter, R varied from 0.86 to 0.96 for the first reading and from 0.74 to 0.96 for the second reading.

Conclusion: The electronic caliper technique is an accurate method for measuring JSW in the hip. This technique seems to be reproducible, is simple, and could be used for routine evaluation. Further validation is required, with the measurement of serial X-rays from the same patients.

Key words: Osteoarthritis, Hip, Joint space narrowing, Caliper.

Introduction

The assessment of osteoarthritis (OA) is routinely based on evaluation of pain and functional disability. Neither of these clinical criteria is strongly correlated with the anatomical progression of the disease. However, we need an accurate technique for assessing the progression of joint damage in view of the development of disease-modifying drugs in OA. Joint space narrowing (JSN), along with osteosclerosis, subchondral cysts and osteophytosis, is one of the indicators of OA progression[1]. The assessment of JSN on standard X-rays is usually selected as the primary end point in trials evaluating the potential structure modifying effect of drugs for treating OA in the hips and knees.

Several new techniques have been proposed for the measurement of JSN in OA of the hips and knees, most involving the measurement of joint space at its narrowest point[2–4]. A manual technique based on the use of a 0.1 mm graduated magnifying glass was proposed by Lequesne *et al.*[5,6]. The magnifying glass is placed over the X-ray either directly, or after a short pencil stroke has been used to indicate the subchondral bone contours at the relevant site. A technique for the quantitative assessment of knee and hip joint spaces by computer analysis of digitally stored X-rays has recently been proposed[7,8]. This technique can be used to evaluate both joint space width and joint surface area.

In this study, we used an electronic caliper to measure joint space width (JSW) for hips on plain radiographs. The corresponding femoral head diameter was also determined to correct for variations due to differences in magnification. We took measurements for normal, OA and arthritic joints to validate this technique and determined interobserver and intraobserver variability.

Material and methods

X-RAYS

We selected 100 standard, non-digitized, non-reduced frontal weight-bearing roentgenograms of the pelvis. Fifty X-rays showed OA changes according to the ACR criteria[9], 30 showed changes related to inflammatory rheumatisms or chondrocalcinosis and 20 were normal.

Received 4 February; accepted 8 February 2002.
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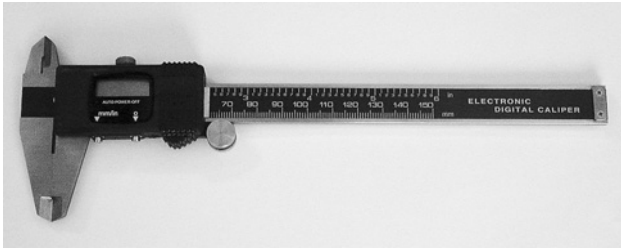

Fig. 1. Photograph of the electronic caliper.

MEASUREMENT OF JOINT SPACE WIDTH

The X-ray films were pooled and each was randomly assigned a number from 0 to 100. All films were read twice by each of two rheumatologists (senior rheumatologist: PH; junior rheumatologist: AA) and two radiologists (senior radiologist: EP; junior radiologist: DM). All readers participated in a training session before the beginning of the study. Each X-ray was examined twice by each observer, with a minimum of four weeks separating the two examinations. The readers were blinded to the identity of the patients.

An electronic digital caliper (Codiam Scientific, France) (Fig. 1), calibrated for the 0–150 mm scale, was used to measure both JSW in the vertical position at the center of the femoral head and the diameter of the femoral head. We determined femoral head diameter to take into account variation due to differences in magnification between the digitized X-rays. These two measurements were taken for both hips on each film.

In some cases, it was not possible to measure femoral head diameter in the vertical position at the center of the femoral head, due to the oblique angle of the femoral neck. In such cases, femoral head diameter was measured as near as possible to the vertical.

For reasons of simplicity and clarity, only the results concerning the right hip are presented. Among these 100 right hips, there were 38 with OA, 18 inflammatory and 44 were normal.

STATISTICAL ANALYSIS

We used the statistical methods described by Fleiss[10] for analysis of the reliability of quantitative data. Intraclass correlation coefficients (R) and 95% confidence intervals were calculated[11]. The intraclass correlation coefficient expresses the relative magnitudes of the two components of total variability [i.e. the biological variability (between subject variability: σ^2BP) and random error (σ^2error or random error)] for a series of measurements on different subjects.

$$R = \frac{\sigma^2 \mathrm{BP}}{\sigma^2 \mathrm{BP} + \sigma^2_{\mathrm{error}}}$$

is the coefficient of correlation between repeated measurements for a subject. *R* values close to 1 ($R>0.8$) indicate satisfactory reliability. Calculations were performed separately for the joint space narrowing score and femoral head diameter score.

Table I
Joint space width, diameter of the femoral head and ratio of these two measurements

	JSW	FHD	Ratio
Rh1			
1	4±1.5	52.6±4.7	0.08±0.03
2	4±1.5	54.1±5.4	0.08±0.03
Rh2			
1	3.8±1.4	52.4±4.8	0.07±0.03
2	3.7±1.4	52.6±4.6	0.07±0.03
R1			
1	4.3±1.5	51.1±4.9	0.08±0.03
2	4.2±1.5	51.4±4.8	0.08±0.03
R2			
1	4±1.4	52.1±4.7	0.08±0.03
2	3.9±1.4	51.9±5	0.08±0.03

Results are given as mean±S.D. (mm).
JSW: joint space width; FHD: femoral head diameter; ratio: joint space width/diameter of the femoral head ratio for the right hip.
Rh1: junior rheumatologist; Rh2: senior rheumatologist; R1: junior radiologist; R2: senior radiologist.
1: first reading; 2: second reading.

Spearman's rank correlation coefficient (*r*) was calculated to assess the correlation between the scores produced by the different methods. SAS/STAT software[12] was used for calculations.

In a complementary analysis, we used the graphical method proposed by Altman and Bland[13], which focuses on the mean and variability of differences between pairs of repeated measurements. A scatter plot of the difference between measurements against their mean can be used to detect major deficiencies in individual reliability that may remain hidden if global reliability statistics such as intraclass correlation coefficients are used. This plot can also be used to investigate possible relationships between measurement error and true values, estimated by the mean.

Results

The various scores obtained are shown in Table I. Results are given for each observer and for each reading. Joint space width varied from normal radiographs (maximum score: 7.6 mm) to maximal joint space narrowing (minimum score of 0). The diameter of the femoral head was between 36.3 mm and 69.3 mm. The ratio of joint space width/diameter of the femoral head was determined to take into account variation due to differences in the magnification of digitized films. This ratio was between 0 and 0.16.

Tables II and III show the results of the statistical analysis, with intraclass correlation coefficients (*R*) and 95% confidence intervals.

For the JSW of the right hip, the intraclass correlation coefficient was between 0.96 and 0.99 for intraobserver reliability. The level of reliability was similar for analysis of the diameter of the femoral head (R: 0.84 to 0.98) and for the ratio of these two measurements (0.96 to 0.99) (Table II).

The most reliable measurements of joint space width (i.e. those with the highest intraclass correlation coefficients) were those made by the senior radiologist,

Table II
Intraobserver variability of joint space width and diameter of the femoral head measurements

	JSW	FHD	Ratio
Rh1	0.97 (0.96–0.98)	0.84 (0.78–0.88)	0.96 (0.95–0.97)
Rh2	0.97 (0.96–0.98)	0.97 (0.96–0.98)	0.97 (0.96–0.98)
R1	0.96 (0.95–0.97)	0.98 (0.97–0.99)	0.96 (0.95–0.97)
R2	0.99 (0.98–0.99)	0.98 (0.98–0.99)	0.99 (0.98–0.99)

Results are given as R: intraclass correlation coefficient with 95% confidence interval.
JSW: joint space width; FHD: femoral head diameter; ratio: joint space width/diameter of the femoral head ratio for the right hip.
Rh1: junior rheumatologist; Rh2: senior rheumatologist; R1: junior radiologist; R2: senior radiologist.

Table III
Reliability of the scores obtained for the joint space width of the right hip

	Rh1	Rh2	R1	R2
Rh1	0.97 (0.96–0.98)	0.93 (0.91–0.95)	0.96 (0.94–0.97)	0.96 (0.95–0.97)
Rh2	0.96 (0.94–0.97)	0.97 (0.96–0.98)	0.88 (0.84–0.91)	0.93 (0.90–0.95)
R1	0.95 (0.93–0.96)	0.91 (0.89–0.94)	0.96 (0.95–0.97)	0.95 (0.93–0.96)
R2	0.96 (0.95–0.97)	0.96 (0.95–0.97)	0.93 (0.90–0.95)	0.99 (0.98–0.99)

Results are given as R: intraclass correlation coefficient with 95% confidence interval.
Results below the diagonal are those for the first reading and results above the diagonal are those for the second reading.
Rh1: junior rheumatologist; Rh2: senior rheumatologist; R1: junior radiologist; R2: senior radiologist.

followed by those made by the two rheumatologists. The lowest *R* values were obtained for the junior radiologist, particularly for analysis of joint space width for the left hip.

In assessments of interobserver reliability for the measurement of JSW, *R* varied from 0.91 to 0.96 for the first reading and from 0.88 to 0.96 for the second analysis (Table III). In assessments of interobserver reliability for the measurement of femoral head diameter, *R* varied from 0.86 to 0.96 for the first reading and from 0.74 to 0.96 for the second reading (data not shown).

Similar results were obtained for the left hip concerning the joint space width, the diameter of the femoral head as well as the ratio of these two measurements (data not shown).

Figures 2–4 show plots for pairs of measurement scores of the JSW, the femoral head diameter and the ratio of the two measurements for the senior radiologist who performed the most reliable measurements.

The differences between the two measurements did not increase with the value of the scores. Indeed, the largest differences were recorded for intermediate or low values, for which it was more difficult to determine the reference points.

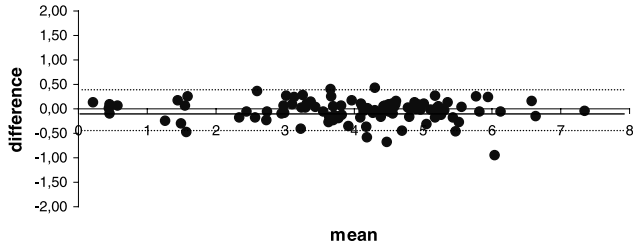

Fig. 2. Bland and Altman graphical representation of intraobserver reproducibility for the measurement of joint space width. We used the graphical method proposed by Altman and Bland[13] which focuses on the mean and variability of differences between pairs of repeated measurements (see Methods section). The figure shows plots for pairs of measurement scores of the JSW for the senior radiologist for the right hip. Values are given in mm. Mean = −0.03; S.D. = 0.22. 95% of the differences are between −0.48 and 0.41.

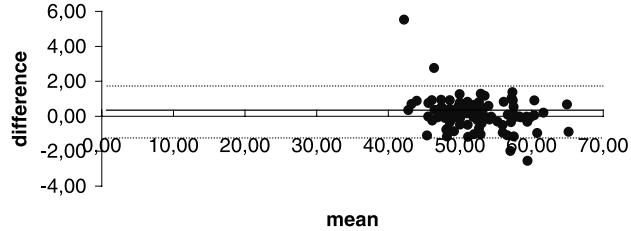

Fig. 3. Bland and Altman graphical representation of intraobserver reproducibility for the measurement of the femoral head diameter. We used the graphical method proposed by Altman and Bland[13] which focuses on the mean and variability of differences between pairs of repeated measurements (see Methods section). The figure shows plots for pairs of measurement scores of the femoral head diameter for the senior radiologist for the right hip. Values are given in mm. Mean = 0.14; S.D. = 0.92. 95% of the differences are between −1.70 and 1.99.

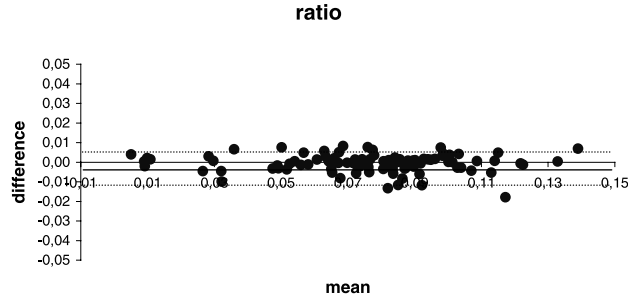

Fig. 4. Bland and Altman graphical representation of intraobserver reproducibility for the measurement of the ratio joint space width/femoral head diameter. We used the graphical method proposed by Altman and Bland[13] which focuses on the mean and variability of differences between pairs of repeated measurements (see Methods section). The figure shows plots for pairs of measurement scores of the ratio joint space width/femoral head diameter for the senior radiologist for the right hip. Values are given in mm. Mean = −0.0005; S.D. = 0.0045. 95% of the differences are between −0.01 and 0.008.

Discussion

This study was designed to evaluate the properties of a new method for the measurement of joint space narrowing (JSN) in OA patients. The progression of JSN, although not specific, is considered to be the best available marker of

disease progression, provided that an accurate method of evaluation is available[1].

The progression of OA is unpredictable in most patients and the progression of JSN differs greatly between patients[14]. However the rapidity of the JSN overtime has been shown to be associated with worsening of pain and disability[15]. It may remain stable for a long period in some patients whereas the joint space may be completely destroyed in a matter of weeks in others. Pain, functional disability and changes visible on X-ray are the main factors taken into account when deciding whether to perform total joint replacement. Some drugs currently prescribed to OA patients as slow-acting drugs for the treatment of symptoms may also have disease-modifying effects. We therefore need a simple and reliable method for measuring JSW that is easy to use in clinical practice.

Conventional X-rays are considered to be sufficient for evaluation of the progression of JSN[16]. The fact that a difference of the width of the joint space of the hip between supine and weight-bearing anteroposterior radiographs is observed is a matter of controversy[17,18]. The global scoring method of evaluation, proposed by Kellgren and Lawrence, is not sensitive enough for the follow-up of OA patients[19,20]. Separate scoring of the various lesions can increase the sensitivity of the method[21].

Various techniques have been developed for the measurement of joint space width in patients with OA of the hips and knees[2–8]. Most of these techniques have acceptable levels of reproducibility and good metrologic properties. JSW is usually measured at the narrowest point, where structural progression of the disease is most likely to occur. In this study, which may be considered to be a preliminary validation procedure, JSW was measured in the vertical position at the center of the femoral head, to ensure that all measurements were made at the same point, or as near as possible to it.

Manual methods of measurement seem to be more readily applicable for use in clinical practice. The technique based on the use of a magnifying glass with internal graduations of 0.1 mm requires delimitation of the joint space by strokes made with a fine pencil. The strokes can be placed more precisely on the subchondral bone contours with the assistance of a common lens[6]. With trained observers, the interobserver coefficient of variation for this technique varies from 3.6% to 5.7%[5,6]. The manual method with eyepiece yielded in the ECHODIAH study an intraobserver intraclass correlation coefficient of 0.963 and a 2 S.D. maximal possible error of 0.50, very close to the same parameter in Fig. 2 in the present caliper study[15].

The electronic caliper method is a one-step technique, the caliper being applied directly to the joint space margins. This instrument also makes it possible to obtain a direct reading, minimizing the risk of errors. The main drawback of this instrument is the difficulty in pointing out the margins of the joint space, which is not specific to this method of measurement.

Computerized analysis of digitized X-rays was recently proposed as a method for assessing JSN[7,8]. This technique requires high-quality X-rays and a pre-determined procedure for joint positioning, especially for the knees[22]. Computer analysis of this type gives an interobserver coefficient of variation of 3.3% for the hips. One advantage of this method is that it can be used to calculate the area as well as JSN[23]. However, this method remains expensive, requires specific equipment and is used mostly for the evaluation of joint damage progression in clinical trials.

The electronic caliper method gives excellent results, especially in terms of intraobserver reproducibility. This is extremely important in the follow-up of patients by a given physician. All readers had a training session before they began taking measurements. However, the highest intraobserver correlation coefficients were obtained for the senior radiologist, who was the most experienced at reading X-rays. The same trend was observed for all measurements. The lowest intraobserver correlation coefficients were obtained for the junior rheumatologist and the junior radiologist, indicating that the quality of the evaluation depends on the experience of the reader.

A manual method using a graduated eyepiece and a computerized image analysis system have recently been compared for the measurement of hip joint space width[24]. Using the automated method, the intraobserver intraclass coefficient of correlation of minimum interbone distance and mean width of a region of interest of the joint space was 0.98 and 0.94, respectively. The intraclass coeeficients of correlation are clearly the best method to evaluate the intraobserver variability. The values found in this paper are very close to those found in our study with the electronic caliper.

One disadvantage of manual readings is that differences in X-ray magnification may create variation in JSW reading. This variation is detected only by automated methods[23–25]. To take into account the variations due to differences in X-ray magnification, we measured the diameter of the femoral head at the same time as JSW. The JSW/diameter of the femoral head ratio was then used to correct for the variations of this type that might be observed during the follow-up of patients. The correlation coefficients for the diameter of the femoral head were similar to those for JSW. However, since this is not a longitudinal study, the issue of variation of the femoral head diameter is not relevant in the present in the absence of comparison with another film or with a 'gold standard'. One disadvantage of our method, as for other manual methods, is that measurements are not possible if cartilage narrowing is maximal.

The electronic caliper technique seems to be an accurate method for measuring JSW in the hip. This technique seems to be reproducible, simple, and could be used for routine evaluation in clinical practice. A work is currently in progress to compare the electronic caliper to other methods of measurement of the joint space width which have been previously developed and validated in OA. We also plan to perform a longitudinal study to assess the sensitivity to changes of our method.

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